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Measurement of Road Consistency on Two-Lane Rural Highways in Granada (Spain)

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Abstract

One significant measure of the design quality of a road is consistency. In this study, consistency based on operating speed was calculated in two-lane rural highways of the province of Granada. Three consistency measures were calculated for 506 homogeneous road sections: the relative area, which represents the area bounded by the speed profile and average speed of a road segment, the standard deviation of the operating speed in each design element along the road segment and the consistency model defined by Polus and Mattar-Habib (2004), based on the previous measures introduced. Some discrepancies have been found in the results obtained

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Keywords: Consistency; Two-lane Rural Highways; Relative area, Standard deviation, Spain

1. Introduction

The three principal factors that contributing to the occurrence of crashes are: human factor, vehicle factor and road infrastructure factor. Treat et al. (1979) consider that the infrastructure, either alone or in combination with other factors, is the cause of more than 30% of traffic crashes.

A measure of the road design is the consistency. Design consistency is defined as the relationship between the geometric characteristics of a highway and those conditions the driver expects to encounter. When the design is consistent with what the driver expects to find, the highway is also consistent. This reduces the possibility of driving errors and unsafe maneuvering (Castro et al. 2008).

The design consistency models are based in four main measures: operating speed, vehicle stability, alignment indices, and driver workload. Operating speed is the most visible indicator of inconsistencies because when the design of a roadway violates driver expectancy, the driver usually reduces the speed of the vehicle (Ng and Sayed, 2004). Operating speed is defined as the speed selected by the drivers when not restricted by other users, i.e., under free flow conditions, and it is normally represented by the 85th percentile speed, denoted as V_{85} (Poe et al. 1996).

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Models based on operating speed to calculate road consistency can be local, applied to a specific geometric element of one road segment; or global, producing a consistency value for the whole road segment. As regards global models, Polus and Mattar-Habib (2004) developed a consistency model C_2 (Eq 1) to assess the consistency of whole road segments. Their model is based on two new consistency measures. The first is the relative area bounded between the operating speed profile (representing the V_{85} for each element of the road segment) and the average weighted operating speed (Ra) (Eq 2). The second one is the standard deviation of the operating speeds at every element of the road segment (σ) (Eq 3).

$$C_2 = 2.808 \cdot e^{-0.278 \cdot [R_a \cdot (\sigma/3.6)]} \tag{1}$$

where:

C_2 = Global consistency model according Polus and Mattar-Habib (2004) (m/s)

R_a= Relative area measure of consistency (m/s)(Eq 2)
σ = Standard deviation of operating speed (km/h) (Eq 3)

$$R_a = \frac{\sum_{i=1}^{n} a_i}{L} \tag{2}$$

where:

a_i= Area, between the speed in each element of profile and average speed (m^2/s)
L = Road segment lenght (km)

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (V_{85i} - \overline{V}_{85})^2}{n}} \tag{3}$$

where:

n = Numberof elements along a road segment

V_{85i} = Operating speed on each element i (tangent or curve) (km/h)
$\overline{V}_{85}$= Average operating speed (km/h):

$$\overline{V}_{85} = \frac{\sum_{i=1}^{n} V_{85i} L_i}{L}, \tag{4}$$

where:

L_i =i element length of the road segment (km)

The thresholds established by Polus and Mattar-Habib (2004) were: For C_2: poor when C_2 was lower than 1 m/s, acceptable when it was between 1 m/s and 2 m/s and good when C_2 was higher than 2 m/s; For Ra: poor when Ra was higher than 2 m/s, acceptable when it was between 1 m/s and 2 m/s and good when Ra was lower than 1 m/s; For σ: poor when σ was higher than 10 km/h, acceptable when it was between 5 km/h and 10 km/h and good when σ was lower than 5 m/s.

Currently other authors have developed global models of consistency but are less well known. For example, Camacho-Torregrosa et al. (2013) put forth a new model of consistency based on data acquired by continuous speed profiles. For each road segment, they relate the speed profile with the geometric variables of the road segment and with crash statistics for the segment. The proposed consistency index relates the average operating speed with the average speed reduction on the road segment. García et al. (2013) developed a new consistency model for evaluating the performance of tangent-to-curve transitions on two-lane rural highways, based on the Inertial Consistency Index (ICI) defined for each transition. This was calculated at the beginning point of the curve, as the difference between the average operating speed of the previous 1 km road segment (inertial operating speed) and the operating speed at this point. The thresholds set for this new index were considered good when ICI was lower than 10 km/h; poor when ICI was higher than 20 km/h; and fair in between.

The main objective of this study is to calculate consistency in two-lane rural highways of the province of Granada (Spain), according to different measures put forth by Polus and Mattar-Habib (2004) and analyze the results.

The paper is organized in six major sections. Section 1 provides an introduction and the description of different consistency models based on operating speed,. Section 2 presents the data and methodology, while in section 3 the results and discussion are expounded. Finally, the last section briefly offers the main conclusions of the study.

2. Data and methodology

2.1 Data

Data were obtained from the General Direction of Roadways, governed by the Andalusian Regional Government. Two-lane rural highways in the province of Granada (Spain) were analyzed. Portions of the roadway within small towns or speed zones, or in the vicinity of intersections with stop signs or traffic signal control on the major road were discarded, as were intersections with major changes in Annual Average Daily Traffic (AADT), and passing or climbing lanes.

The road length obtained after eliminating all these sections was 978 km (1,956 km if considering both directions of circulation), with a minimum AADT of 210 veh/day and a maximum of 8,681 veh/day.

2.2 Methodology

Firstly, each road was divided into individual horizontal curves and tangents. The next step was to subdivide the sample into homogeneous road segments. Taking into account the AADT, Curvature Change Rate (CCR) and average paved Width (W), (Cafiso et al., 2008), 506 homogeneous road segments were obtained. Table 1 shows the minimum, maximum, average values and standard deviation of the length of the sections, as well as the variables used to divide the sample into 506 homogeneous sections:

Table 1. Summary of the characteristics of homogeneous road sections

	Min	Max	Mean	Standard Deviation
Length Sections (km)	0.151	17.141	3.864	3.376
AADT (veh/day)	210	8,681	188.881	2,027.3
CCR (gon/km)	4.7	1,098.05	351.28	310.91
Road Width (m)	5	10	6.2	1.9

Having identified the 506 homogeneous road segments, the operating speed profile for each was built (V_{85} in each road element). This called for establishing a speed on curves and tangents, and deceleration or acceleration rates.

A constant curve speed was adopted. Given the importance of using speed prediction models calibrated according to local conditions (Misaghi and Hassan, 2005), the model of Camacho-Torregrosa et al. (2013) was adjusted for horizontal curves in two-way rural highways in Spain. The model thus made it possible to obtain the V_{85} in terms of the radius of the curve.

The tangent speed value taken was 110 km/h (derided speed according to Camacho-Torregrosa et al., 2013).

The acceleration and deceleration rates proposed by Fitzpatrick et al. (2000) for horizontal curves were selected, which are also determined as a function of the radius of the curve.

The operating speed profiles were calculated in each homogeneous road segment.

3. Results and discussion

Consistency was calculated for each road section from the speed profile.

The three consistency measures established by Polus and Mattar-Habib (2004) were obtained: the simple measures Ra and σ, and the model that encompasses them, C_2. Table 2 shows the percentage of road sections classified as poor, acceptable or good, according to Ra, σ and C_2, as well as statistical values obtained for these measures of consistency.

Table 2. Values of consistency measures Ra, σ, C_2

Consistency Measures	Units	Good (%)	Acceptable (%)	Poor (%)	Mean	Min	Max	Standard Deviation
Ra	m/s	8.50	35.97	55.53	2.03	0.00	4.28	0.70
σ	km/h	6.52	34.19	59.29	10.86	0.00	26.50	3.85
C_2	m/s	5.54	16	78.46	0.69	0.02	2.81	0.62

Table 2 shows that, although C_2 is based on Ra and σ, the percentage of the classified road sections in the poor category according to C_2 (78.46%) is much higher than the percentage of classified road sections in the same category according to Ra (55.53%) or according to σ (59.29%). Furthermore, as shown in Table 3, the average value of C_2 for the road sections of study is

0.69 (clearly poor, according to thresholds established by Polus and Mattar-Habib (2004)), while the average value of Ra is 2.03 (poor, but nearly acceptable) and the average value of σ is 10.86 (poor, but bordering on acceptable).

Figure 1 shows the number of classified road sections in each category according to consistency measures Ra and σ. Figure 2 the number of road sections classified according to C_2:

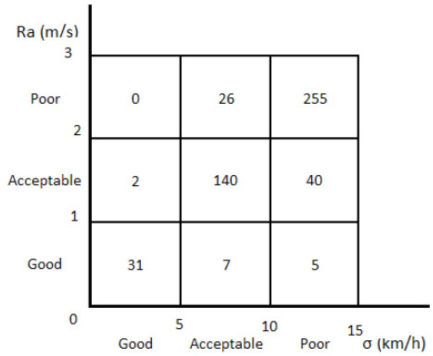

Figure 1. Classification of the 506 road sections according to Ra and σ

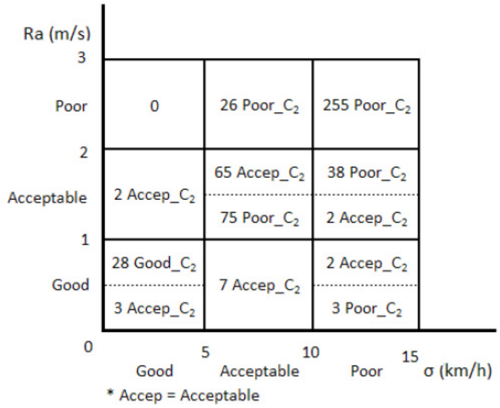

Figure 2. Classification of the 506 road sections according to Ra, σ and C_2

The most remarkable observation from Figure 1 and 2 is that 140 road sectionsare acceptable, in view of Ra and σ (Figure 1); however if these road sections were classified according to C_2 (Figure 2), less than half (65 road sections) would be acceptable, and the remaining 75 are classified as poor. Analysis of the studied road sections through different consistency measures established by Polus and Mattar-Habib (2004) (Ra, σ and C2) thus shows that C2 classifies as poor many road sections which, according to Ra and σ, are acceptable. In other words, C2 may be too demanding and conservative.

To clarify previous statements, Ra as function of C_2 is represented (Figure 3). In general, the road sections classifications according to Ra and C_2 coincide in almost all the quadrant. For example, in the central quadrant of Figure 3, almost all road sections are acceptable according to Ra and acceptable according to C_2. However, in the obliquely lined quadrants the road sections are acceptable according to Ra yet they are classified as poor according to C_2. In principle, if the intention is that the categories according to Ra and C_2 coincide, these road sections should be situated in the central quadrant. The same would be appreciated if σ was represented as function of C_2.

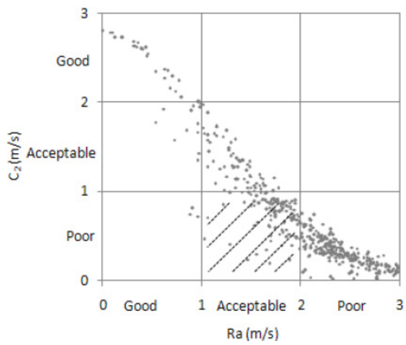

Figure 3. C_2 as a function of Ra

From previous observations it can be deduced that the formulation of C_2 is far more restrictive than the formulation of Ra and σ, at least for the studied roads. This may be because Polus and Mattar-Habib (2004)created the global model C_2 with an exponential function (characterized for having large slopes), in which the consistency C_2 decreases rapidly when the two simple measures of consistency (Ra and σ) increase. If this exponential curve (appearing by drawing the points in Figure 3) had a smooth slope, the points in the obliquely lined quadrant could be placed in the central quadrant. This would ensure that the categories of C_2 are more in line with those of Ra and σ.

Also, some inconsistencies have been found in the modelPolus and Mattar-Habib (2004). The surface that includes the combination of values of C_2, according to Ra and σ is represented in three dimensions, (Figure 4). In this figure σ is represented on the x-axis, Ra on the y-axis, and the consistency (C_2) on the z-axis.

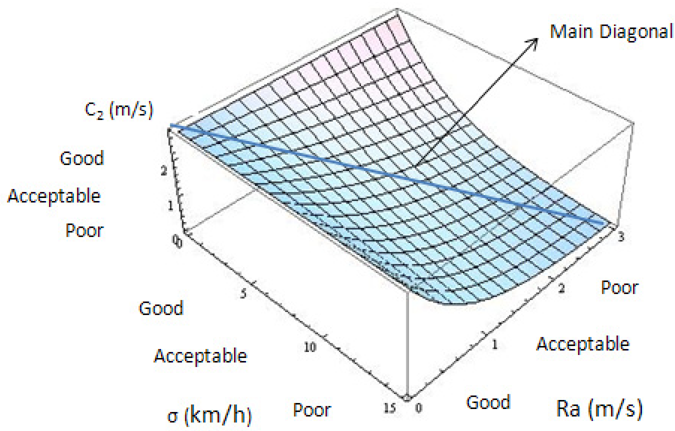

Figure 4. C_2 and C_4 as a function of σ and Ra

If Figure 4 is analyzed, it can be observed that C_2 is decreasing along the main diagonal from good to poor consistency. The behavior of this function is reasonable because decreases along the main diagonal from good to poor consistency (C_2 is good if Ra and σ are good and C_2 is poor if Ra and σ are poor). However the function behaves not very reasonable along the secondary diagonal (perpendicular to the main diagonal). C_2 considers that the consistency is worse (lower value) at any point on the main diagonal than at any point along a segment perpendicular to the main diagonal of that point (being maximum at the end of the secondary diagonal). It is not very logical the behavior of the function of C_2 because for example a section in which Ra and σ are acceptable (secondary diagonal center) would have a consistency C_2 superior to a section in which Ra is good and σ poor or vice versa (secondary diagonal ends). Also, as seen in Figure 4, the value of consistency C_2 is very high at the end of the secondary diagonal, which is not logical; it gives a very good consistency value (equal to that of a combination in which both Ra and σ are good) for a combination of poor Ra and good σ, and vice versa.

Thus, it could be said that C_2 gives some consistency values that are not very logical both on the main diagonal and at the points away from it.

The authors of this paper proposed as future research lines create a new consistency model that improves some Polus and Mattar-Habib (2004) model aspects.

4. Conclusions

The global consistency model defined by Polus and Mattar-Habib (2004) has been estimated at 506 road sections of two-lane rural highways of the province of Granada (Spain). The calculation of this global model, based on the parameters of Relative area (Ra) and Standard deviation (σ), in our field of study, revealed two main observations. The first one is that the model of Polus and Mattar-Habib (2004) is quite conservative because there are road sections, that having acceptable values of Ra and σ, are classified as poor according to the global model of Polus and Mattar-Habib (2004). The second observation is that some consistency values, obtained with this model can be improved by certain combinations of values of Ra and σ. For example it has been observed that the model of Polus and Mattar-Habib (2004) assigns the same value of consistency to a road section in which

the measures Ra and σ are good as well as in a section in which Ra is good and σ is poor or vice versa.
These observations have led to propose as future research line a new consistency model that improves some Polus and Mattar-Habib (2004) model aspects.

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